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(71) Applicant *(for all designated States except US)*: **IWATANI INTERNATIONAL CORPORATION** [JP/JP]; 4-8, Hommachi 3-chome, Chuo-ku, Osaka-shi, Osaka 541-0053 (JP).

(71) Applicants and
(72) Inventors: **TAMURA, Masamitsu** [JP/JP]; 3-6-23, Kashiwanoha, Kashiwa-shi, Chiba 277-0882 (JP). **GOTO, Shinichi** [JP/JP]; 3-4-12, Matsumaedai, Moriya-machi, Kitasouma-gun, Ibaraki 302-0102 (JP).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **SUGIYAMA, Kouseki** [JP/JP]; c/o Iwatani International Corporation Tokyo Headquarters, 3-21-8, Nishi Shinbashi, Minato-ku, Tokyo 105-0003 (JP). **KAJIWARA, Masataka** [JP/JP]; c/o Iwatani International Corporation Tokyo Headquarters, 3-21-8, Nishi Shinbashi, Minato-ku, Tokyo 105-0003 (JP). **SAGARA, Makoto** [JP/JP]; c/o Iwatani International Corporation Tokyo Headquarters, 3-21-8, Nishi Shinbashi, Minato-ku, Tokyo 105-0003 (JP).

(74) Agent: **KANDA, Fujihiro**; Yuasa And Hara, Section 206, New Ohtemachi Bldg., 2-1, Ohtemachi 2-chome, Chiyoda-ku, Tokyo 100-0004 (JP).

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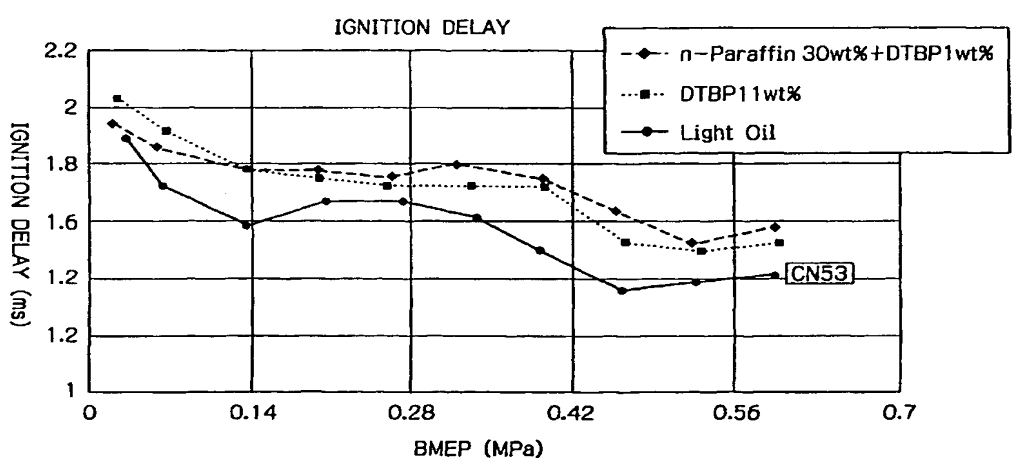
(54) Title: LIQUEFIED GAS FUEL FOR COMPRESSION IGNITION ENGINES



(57) Abstract: Disclosed is a liquefied gas fuel, which can reduce emissions of air pollutants, such as black smoke, particulate matter, NOx and SOx in an exhaust gas of a compression ignition engine. The liquefied gas fuel comprises liquefied petroleum gas added with a radical generating agent, a lubricity improving agent and liquid hydrocarbon, or dimethyl ether added with the lubricity improving agent.

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DESCRIPTION

LIQUEFIED GAS FUEL FOR COMPRESSION IGNITION ENGINES

TECHNICAL FIELD

The present invention relates to a liquefied gas fuel for a compression ignition engine. In particular, the present invention relates to the liquefied gas fuel composed of a liquefied petroleum gas (LPG) or a dimethyl ether (DME), which can reduce emissions of black smoke, particulate matter, NOx, and other air pollutants, while providing a highly efficient and stable operation of the compression ignition engine.

BACKGROUND ART

Because of their high thermal efficiency, compression ignition engines are generally used as driving sources for industrial vehicles such as trucks, or as power sources for industrial machines. However, a conventional compression ignition engine using diesel oil such as light oil or heavy oil, has the disadvantage in that it emits a large amount of black smoke, particulate matter, NOx, and other air pollutants. To overcome this disadvantage, it has been suggested that LPG or DME should be used as a fuel for the compression ignition engine, and it has also been suggested that a radical generating agent should be added thereto in order to improve a low cetane number of the LPG (JP-A-11-335681).

Although the liquefied petroleum gas (LPG) is made by compressing a gas composed mainly of low-molecular hydrocarbon, such as propane (C_3H_8), propylene ($CH_3CH{=}CH_2$), or butane (C_4H_{10}), to be liquefied at a room temperature and is suitable for transportation, it has a lower self-ignitability (cetane number), and therefore, when the LPG is used as a fuel for a compression ignition engine without any additives,

it is necessary to increase the compression ratio up to 26 or higher. Such a high compression ratio, however, decreases a thermal efficiency of the compression ignition engine and generates great noise and vibration thus is considered impractical.

Although it has been suggested that a radical generating agent should be added to the LPG in order to improve the lower cetane number, it has exhibited the disadvantage in that a high price thereof makes it difficult for the agent to be used.

Dimethyl ether (DME), which is gaseous at room temperature, is liquefied when compressed up to 15kgf/cm^2 or higher, so that it can be supplied to the compression ignition engine with a fuel injection pump. The DME offers the advantages that it has the same level of cetane number as the light oil, and generates an exhaust gas with low concentration of NOx and little smoke when used as the fuel for the compression ignition engine.

However, since the LPG and the DME respectively have a lower viscosity in comparison with that of the diesel oil, a leak of the fuel could occur to a great degree in, for example, a fuel injection pump and a fuel injection nozzle, which is problematic from the viewpoints of safety, fuel efficiency and cost effectiveness.

Further, since the liquefied gas, such as the LPG or the DME, has a lower lubricity in comparison with the diesel oil, the use of such liquefied gas as the fuel for the compression ignition engine could cause another problem wherein a sliding friction section of, for example, a fuel injection valve is subject to wear to a greater degree in comparison with the case where the diesel oil is used, resulting in a malfunction thereof after a certain period of operation.

DISCLOSURE OF THE INVENTION

An object of the present invention is to solve the above problems associated with the prior art so that a LPG or a DME can be economically used as a fuel for a compression ignition engine, and to resolve the problem of gas leakage so as to improve safety. To accomplish the object above, according to the present invention, a fuel to be supplied to a combustion chamber of the compression ignition engine with a compression ratio set in a range of 11 to 23 is composed of LPG added with a radical generating agent, which is further added with liquid hydrocarbon with the carbon number of 5 to 20 by an amount of 5 to 40 wt%.

The radical generating agent is composed, for example, of organic peroxide including di-t-butyl peroxide, and, in concrete, comprises at least one compound selected from the group consisting of nitrate, nitrite, organic peroxide and azo compound. The liquid hydrocarbon to be added may be at least one element selected from the group consisting of normal paraffin, naphtha, kerosene, light oil and heavy oil.

Another object of the present invention is to make it possible for the LPG or the DME to be used as the fuel of a compression ignition engine and to reduce an amount of fuel leak from a fuel system thereof. To achieve the object above, according to a feature of the present invention, a fuel to be supplied to a combustion chamber of a compression ignition engine is a liquefied gas composed of LPG added with a radical generating agent or DME, which is further added with at least one element selected from the group consisting of liquid paraffin, normal paraffin and light oil so as to improve a viscosity.

Still another object of the present invention is to provide a liquefied gas fuel for a compression ignition engine, which can prevent wear of a sliding friction section of, for example, a fuel injection valve while the liquefied

gas fuel is being used, otherwise resulting in a malfunction of the sliding friction section. In order to accomplish the above object, according to the present invention, the liquefied gas fuel for a compression ignition engine comprises DME or LPG added with a radical generating agent, which is further added with a lubricity improving agent.

The lubricity improving agent comprises one or more element(s) selected from the group consisting of higher alcohol, alkyl ester and fatty acid, each being of straight chain carbon number of 8 to 14, which is added by 10 mass ppm to 5 wt %. Liquid hydrocarbon may be further added as a cetane number improving adjuvant. Said liquid hydrocarbon may be made from a crude oil and/or a natural gas, and may be at least one of normal paraffin, naphtha, kerosene, light oil and heavy oil.

FUNCTION OF THE INVENTION

According to the present invention, since LPG is added with the liquid hydrocarbon with the carbon number of 5 to 20 by 5 to 40 wt %, the cetane number improving effect (the ignition delay reducing effect) of the radical generating agent can be amplified, so that the content of the expensive radical generating agent can be significantly reduced.

According to the present invention, the thermal efficiency can be kept at the same level as that in the case when using the diesel oil, such as the light oil or the heavy oil, while the yield of black smoke can be substantially decreased in comparison with the case of light oil.

Since the liquid hydrocarbon used as the additive includes little sulfur content similar to the LPG, there will be no generation of air pollutants such as SOx, nor degradation in the catalytic activity by poisoning of the sulfur content, which makes it possible to reduce the NOx by an application of a post-treatment using, for example, a

denitrifying catalyst.

According to a feature of the present invention, since the liquefied gas fuel composed of the LPG or the DME to be supplied to the combustion chamber of the compression ignition engine is added with at least one element selected from the group consisting of liquid paraffin, normal paraffin and light oil so as to improve the viscosity, a good sealing performance as well as a high efficiency in fuel consumption may be accomplished.

According to the present invention, since the fuel to be supplied to the combustion chamber of the compression ignition engine is added with the lubricity improving agent, a burning and wear of the fuel supply and fuel injection nozzles may be prevented.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a graph illustrating a change in a concentration of black smoke for the LPG added with normal paraffin;

Fig. 2 is a graph illustrating a change in a concentration of NOx for the LPG added with the normal paraffin;

Fig. 3 is a graph illustrating an ignition delay in contrast, when an additive amount of normal paraffin and DTBP is varied;

Fig. 4 is a graph illustrating an ignition delay in contrast, when different amounts of normal paraffin are added to LPG;

Fig. 5 is a graph illustrating an amount of gas leak in a fuel injection pump as a function of straight chain carbon number of higher alcohol, alkyl ester or fatty acid added as a lubricity improving agent;

Fig. 6 is a graph illustrating a relation between an additive amount of a lubricity improving agent and an amount

of gas leak in a fuel injection pump;

Fig. 7 is a graph illustrating a relation between an additive amount of liquid hydrocarbon and an amount of gas leak in a fuel injection pump;

Fig. 8 is a graph illustrating a relation between a pressure level within a cylinder and a needle lift of a fuel injection nozzle when a fuel injection pressures is varied;

Fig. 9 is a graph illustrating an emission amount of NOx for a different injection-valve opening pressures of the fuel injection nozzle; and

Fig. 10 is a schematic diagram of a compression ignition engine of an embodiment according to the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

In order to make it possible to drive a compression ignition engine by using LPG, the LPG was added with a radical generating agent and liquid hydrocarbon composed of normal paraffin with the carbon number of 5 to 20 by a range of 5 to 40 wt%. As the radical generating agent, at least one element was selected from the group consisting of nitrate, nitrite, organic peroxide and azo compound.

The reason why the normal paraffin with a carbon number of 5 to 20 has been selected therefor is that a boiling point is too high if the carbon number is equal to or greater than 21, which is unsuitable for the fuel to be used in the compression ignition engine, and that if the carbon number is equal to or less than 4, it is exactly representative of the LPG, which means the ignitability is never improved. Further, the reason why the amount of liquid hydrocarbon added thereto is set in the range of 5 to 40 wt% is that the level of exhausted black smoke is equal to or greater than that in the case of using the light oil if it exceeds 40 wt%, and that the effect of improvement is insufficient if it is below 5 wt%.

(EXAMPLE 1)

A compression ignition engine used in this example has a piston displacement of 1,858 cc, a compression ratio of 17, an engine speed of 1500 rmp, a plunger diameter of 12 mm, a fuel injection pressure of 16.3 Mpa, and a fuel injection timing set at 15 degrees before the top dead center. Liquid butane with varied amount of normal paraffin added thereto was used as a fuel. The emission amounts of black smoke and nitrogen oxides in this example were measured and are shown in Figs. 1 and 2 respectively. The added normal paraffin was a mixture with the carbon number of 14 as a central value and dispersed therearound. In addition, for the purpose of comparison, the emission amounts of the black smoke and the nitrogen oxides in the case of the light oil being used as a fuel were measured and are shown in Figs. 1 and 2 respectively.

As shown in Fig. 1, in the fuel added the normal paraffin by 50 wt%, the emission amount of black smoke was almost equal to that by the light oil, while in the fuel added with the normal paraffin by 40 wt%, the emission amount of black smoke was approximately 1/3 of that by the light oil, and in the fuel added with the normal paraffin by 30 wt%, the emission amount of black smoke decreased down to about 1/8 of that by the light oil.

As shown in Fig. 2, in the fuel added with the normal paraffin by 50 wt%, the emission amount of nitrogen oxides increases to be more than that by the light oil, but in the fuel added with the normal paraffin by 40 wt% or 30 wt%, the emission amounts of nitrogen oxides are substantially equal to that by the light oil.

Fig. 3 is a graph illustrating a relation between a brake mean effective pressure and an ignition delay. As can be seen from Fig. 3, the ignition delays are almost same for

the LPG added with the radical generating agent by 11 wt% and for the LPG added with the radical generating agent by 1 wt% and the normal paraffin by 30 wt%.

Fig. 4 is a graph illustrating the ignition delay in contrast for the LPGs added with varied amounts of normal paraffin. Di-t-butyl peroxide (DTBP : organic peroxide) is added as the radical generating agent by 5 wt%. As can be seen from Fig. 4, the ignition delay is 2.0 ms for the case with 5 wt% of the normal paraffin added, which is little different from the ignition delay of 2.1 ms for the case with no normal paraffin added, but the ignition delay is 1.3 ms for the case with 30 wt% of the normal paraffin added, which is approximately a half of the ignition delay for the case with no normal paraffin added.

(EXAMPLE 2)

A compression ignition engine used in this example has a piston displacement of 1,858 cc, a compression ratio of 17, an engine speed of 1500 rmp, a plunger diameter of 12 mm, a fuel injection pressure of 25.5 Mpa, and a fuel injection timing set at 27 degrees before the top dead center. A fuel used is liquid butane added with di-t-butyl peroxide (a radical generating agent) by 5 wt%, which has been further added with long chain alkyl ester (additive ester: a lubricity improving agent) by 100 mass ppm and liquid paraffin (liquid hydrocarbon: a cetane improving adjuvant) by 10 wt%.

Fig. 5 is a graph illustrating a relation between the straight chain carbon number of higher alcohol, alkyl ester or fatty acid, each being added as the lubricity improving agent in the example 2, and an amount of gas leak in the fuel injection pump. As can be seen from Fig. 5, the lowest range of the leak amount falls around the straight chain carbon number of 12 to 14 in the case of higher alcohol being used

as the lubricity improving agent, while the lowest range of the leak amount falls in the straight chain carbon number of 14 in the case of alkyl ester and the fatty acid.

As for the fatty acid with the straight chain carbon number of 12 or less, no effect is observed for reducing the leak amount. Further, since the additives with the straight chain carbon number of 7 or less can not provide sufficient improvement of lubricity, it is desirable to use the additives with the straight chain carbon number equal to or more than 8 and below 14.

Fig 6 is a diagram illustrating a relation between an additive amount of higher alcohol, alkyl ester or fatty acid, and an amount of gas leak in the fuel injection pump in the example 2, in which it is shown that the additive amount less than 10 mass ppm of higher alcohol, alkyl ester or fatty acid is not sufficient to make an effect on improvement. On the other hand, since the additive amount more than 5 wt% produces a negative effect on the combustion exhaust gas, the additive amount of the lubricity improving agent is preferably in a range of 10 mass ppm to 5 wt%.

Further, the use of the higher alcohol increases a friction coefficient at the temperature of 50°C to 60°C and higher. Because the fuel injection pump is usually operated at the temperature around 60°C to 70°C, it is desired that the alkyl ester or the fatty acid is used.

Fig. 7 is a diagram illustrating a relation between an additive amount of liquid hydrocarbon to be added together with the lubricity improving agent, and an amount of gas leak in the fuel injection pump in the example 2, wherein normal paraffin and light oil may be used in addition to said liquid paraffin as the liquid hydrocarbon to be added. As for this additive amount of the liquid hydrocarbon, the higher the additive amount is, the lower the leak amount becomes,

however, an additive amount of more than 30 wt% produces a negative effect on the combustion exhaust gas, resulting in the emission of black smoke and the like, while an additive amount of less than 1 wt% does not have a sufficient effect on the improvement, and therefore the favorable additive amount of the liquid hydrocarbon is within the range of 1 wt% to 3 wt%.

As is obvious from Fig. 7, when no liquid paraffin is added, the amount of gas leak is about 4 liter/min, but when the liquid paraffin is added by 1 wt%, the amount of gas leak decreases to about 3.7 liter/min, and when the liquid paraffin is added by 10 wt%, the amount of gas leak decreases down to about 2.7 liter/min. Further, adding the normal paraffin or the light oil can reduce the amount of the gas leak. The sealing performance is improved more by adding the light oil, the normal paraffin or the liquid paraffin in this order, and these substances have higher compatibility with the liquid gas so as to be uniformly mixed therewith.

Since the liquid paraffin and the normal paraffin are kinds of hydrocarbon and include neither sulfur content nor metal constituent, they produce no negative effect on combustion. Thereby, the leak in the fuel supply system is reduced and the efficiency in fuel consumption can be improved while the combustion quality being retained at a certain level.

As shown in Fig. 7, the amount of gas leak can be reduced by about 60 % with the normal paraffin (the mixture with the carbon number of 14 as a central value and dispersed therearound) added by 30 wt%, and the amount of gas leak can be reduced by about 40 % with the normal paraffin added by 20 wt%. This is because the adding of the normal paraffin increases the viscosity of the liquid gas, thereby successfully sealing the gap in the plunger sliding sections.

In the compression ignition engine employing the fuel described above, since the lubricity improving agent and the liquid hydrocarbon have been added into the fuel to be supplied thereto, the sliding sections of the fuel injection nozzle, fuel injection pump, pressure feed type fuel plunger pump and the like are lubricated with the fuel, so that the wear and malfunction which would, otherwise be caused by insufficient lubrication can be prevented.

When the compression ignition engine was driven using the single substance of liquid butane (100% liquid butane) under the same condition as described above, the horse-power and the engine speed of the engine became unstable 10 minutes after starting subsequently after another few minutes, the engine stopped and could not be restarted. In this case, the wear and burning caused by the insufficient lubrication was observed in the sliding portion of the fuel injection nozzle.

In the above examples 1 and 2, although the liquid butane is employed for the liquid gas, the liquid propane or the mixture of liquid butane and liquid propane may be used. Further, the liquid gas may be the DME and in this case no radical generating agent is required to be added. Naphtha, kerosene, or liquid hydrocarbon such as light oil and heavy oil may be used instead of normal paraffin for a viscosity improving agent.

The substance usable as a radical generating agent includes, in addition to the above-described di-t-butyl peroxide, organic peroxides such as methyl isobutyl ketone peroxide, tris-t-butyl peroxy triazine, 2,5-dimethyl-2,5-di-t-butyl peroxy hexane, 1,1-di-t-butyl peroxy cyclohexane, and 2,2-di-butyl peroxy butane, nitrates such as isooctyl nitrate, isoamyl nitrate, normal amyl nitrate and isopropyl nitrate and ethyl hexyl nitrate, nitrites such as normal propyl nitrite and normal butyl nitrite, and azo compounds.

(EXAMPLE 3)

A compression ignition engine having a piston displacement of 1,858 cc, a compression ratio of 17, an engine speed of 1500 rmp, a plunger diameter of 12 mm, and a fuel injection timing set at 20 degrees before the top dead center was supplied with liquid gas fuel to examine the engine performance and exhaust gas constituents. The liquid gas fuel comprises liquid butane mixed with di-t-butyl peroxide (organic peroxide: a radical generating agent) by 1 wt%, which is further added with long-chain alkyl ester (additive ester: a lubricity improving agent) by 100 mass ppm and normal paraffin (liquid hydrocarbon: a cetane number improving adjuvant) by 30 wt%.

Fig. 8 is a graph illustrating a relation between a pressure within a cylinder for different fuel injection pressures and a needle lift of a fuel injection nozzle obtained under the condition and the fuel of example 3. As can be seen from Fig. 8, the fuel injection pressure, as decreased from the level of 25.5 MPa, makes the ultimate pressure within the cylinder slightly lower and an injection-valve opening time of the fuel ignition nozzle longer. Since LPG has a boiling point lower than that of the diesel oil, it is uniformly diffused within the cylinder and the fuel is continuously injected into the cylinder for a certain period even if it is injected at a low pressure, so that the slow combustion may be carried out in the cylinder. This makes the combustion temperature relatively lower and thereby reduces the emission amount of NOx.

Fig. 9 is a graph illustrating an emission amount of NOx for a different injection-valve opening pressures of the fuel injection nozzle in the example 3. The emission amount of NOx was examined for the different injection-valve opening pressure of the fuel injection nozzle set at 16.3 MPa, 10.2

MPa and also 25.5 MPa which was typical for conventional light oil and was used as control assuming the emission amount of NOx to be 100% under this condition, and according to the test result, the emission amount of NOx exhaust was reduced by about 12 % at the valve opening pressure of 16.3 MPa and by about 24 % at the valve opening pressure of 10.2 MPa.

It is found from Fig. 9, that the valve opening pressure set to be higher than 16 MPa provides less effect on reducing the NOx. Further, the valve opening pressure set to be lower than 5 MPa makes the fuel injection pressure lower than the maximum ultimate pressure within the cylinder, which might cause a back fire to occur. Therefore, the valve opening pressure of the fuel injection nozzle is preferably set to a level of around 5 MPa to 16 MPa.

Fig. 10 is a schematic diagram of a compression ignition engine system of a first embodiment of the present invention. In Fig. 10, the compression ignition engine 1 comprises a storage tank 2 for liquid gas fuel, a fuel supply system 3 extending from the storage tank 2, a fuel injection pump 4 arranged in the fuel supply system 3, and a fuel injection nozzle 5. The fuel injection nozzle 5 is fitted on a tip of a high pressure fuel system extended from the fuel injection pump 4. The liquefied gas fuel stored in the storage tank 2 is a fuel composed of LPG additionally mixed with at least one element selected from a radical generating agent group consisting of nitrate, nitrite, organic peroxide, and azo compound.

A catalyst reactor 8 for reducing NOx is arranged in an exhaust system 7 extending from an exhaust manifold 6 of the compression ignition engine 1. A reducing agent supply system 9 is connected to a portion upstream of the catalyst reactor 8 in the exhaust system 7.

The reducing agent supply system 9 comprises a buffer tank 10 for receiving a fuel leaked from the fuel injection pump 4 and the fuel injection nozzle 5, and a supply pump 11 and a flow channel opening and closing valve 12 which are disposed in a flow channel section extending from the buffer tank 10. The supply pump 11 receives a reducing agent from a reducing agent line 13, which guides the fuel (the reducing agent) from the buffer tank 10 and the storage tank 2. The buffer tank 10 controls or absorbs a pressure fluctuation caused by a change in the discharge of the leaked fuel gas.

The catalyst reactor 8 contains a catalyst composed of metallic oxide as an active constituent for reducing NOx, and is arranged in a location where the temperature of the catalyst may reach its optimal reaction temperature of 250°C to 400°C. Then, the exhaust gas from the engine is added with the leaked fuel and is introduced into the catalyst reactor 8, where the leaked fuel works as the reducing agent to thereby reduce the NOx content in the exhaust gas.

To prevent the reducing effect from being degraded when the catalyst temperature is low, the catalyst temperature is detected so that the amount of the leaked fuel to be added may be controlled based on the detected catalyst temperature. Further, to be responsive to an amount of the exhaust gas varied proportionally to the opening and closing degree of the throttle valve of the engine, the amount of the leaked fuel to be added is controlled based on the opening and closing degree of the throttle valve.

EFFECT OF THE INVENTION

The present invention as defined in the attached respective claims provides the following superior effects. The liquefied gas fuel for a compression ignition engine according to the present invention comprises LPG or DME added with a radical generating agent, which is further added with

a lubricity improving agent. Therefore, the liquefied gas fuel according to the present invention has a highly improved lubricity, so that it can prevent malfunctions of sliding and friction portions of a fuel injection pump, fuel injection nozzle and the like.

Further, when liquid hydrocarbon, which does not include any sulfur content nor metallic constituent, is added together with the lubricity improving agent, the lubricity can be improved without producing any negative effect on the combustion. The addition of the liquid hydrocarbon by 1 wt% to 30 wt% can improve the cetane number without adversely affecting the combustion gas, and also it can improve the viscosity of the fuel so as to decrease a leak amount of the liquefied gas in the fuel injection pump.

According to a feature of the present invention, since the liquefied gas fuel is added with at least one element selected from the group consisting of liquid paraffin, normal paraffin and light oil, the viscosity and sealing performance, and thus an efficiency in fuel consumption can be improved, so that it becomes usable as a fuel for the compression ignition engine without the need to apply any particular treatment, for example, coatings to the fuel injection pump and the fuel injection nozzle.

According to the present invention, by adding the liquid hydrocarbon with the carbon number of 5 to 20 to the LPG by 5 to 40 wt%, the cetane number improving effect of the radical generating agent for the LPG can be amplified, so that the additive amount of the radical generating agent can be significantly reduced. In this case, an emission amount of black smoke can be significantly reduced in comparison with the case where the light oil is used as the fuel, and in addition, an emission amount of nitrogen oxides can reduced. Since the liquid hydrocarbons, such as normal paraffin and

the like, are as cheap as the LPG, the cost increase caused by the addition of the radical generating agent can be kept to a minimum.

Although the radical generating agent is inherently self-decomposable and corrosive, effects on a decomposition rate and corrosion of the radical generating agent can be reduced by the added liquid hydrocarbon such as normal paraffin or the like, so that the safety in storage and transportation can be improved.

CLAIMS

1. A fuel to be supplied to a combustion chamber of a compression ignition engine, said fuel comprising as a major constituent LPG added with a radical generating agent or DME, wherein a major constituent of said LPG is liquid butane or liquid propane or a mixture thereof, and said fuel is further added with a lubricity improving agent.

2. A fuel in accordance with claim 1, further added with liquid hydrocarbon.

3. A fuel in accordance with claim 1 or 2, in which said lubricity improving agent comprises one or more elements selected from the group consisting of higher alcohol, alkyl ester and fatty acid, each being of straight chain carbon number of 8 to 14, which is added to said fuel by 10 mass ppm to 5 wt%.

4. A fuel in accordance with claim 2 or 3, in which said liquid hydrocarbon is at least one of normal paraffin, naphtha, kerosene, light oil and heavy oil.

5. A fuel in accordance with claim 1, further added with a viscosity improving agent.

6. A fuel in accordance with either of claim 5, in which said viscosity improving agent is composed of at least one element selected from the group consisting of liquid paraffin, normal paraffin and light oil.

7. A fuel to be supplied to a combustion chamber of a compression ignition engine with a pressure ratio set at 11 to 23, said fuel comprising LPG added with liquid hydrocarbon with the carbon number of 5 to 20 by 5 to 40 wt% as well as with a radical generating agent.

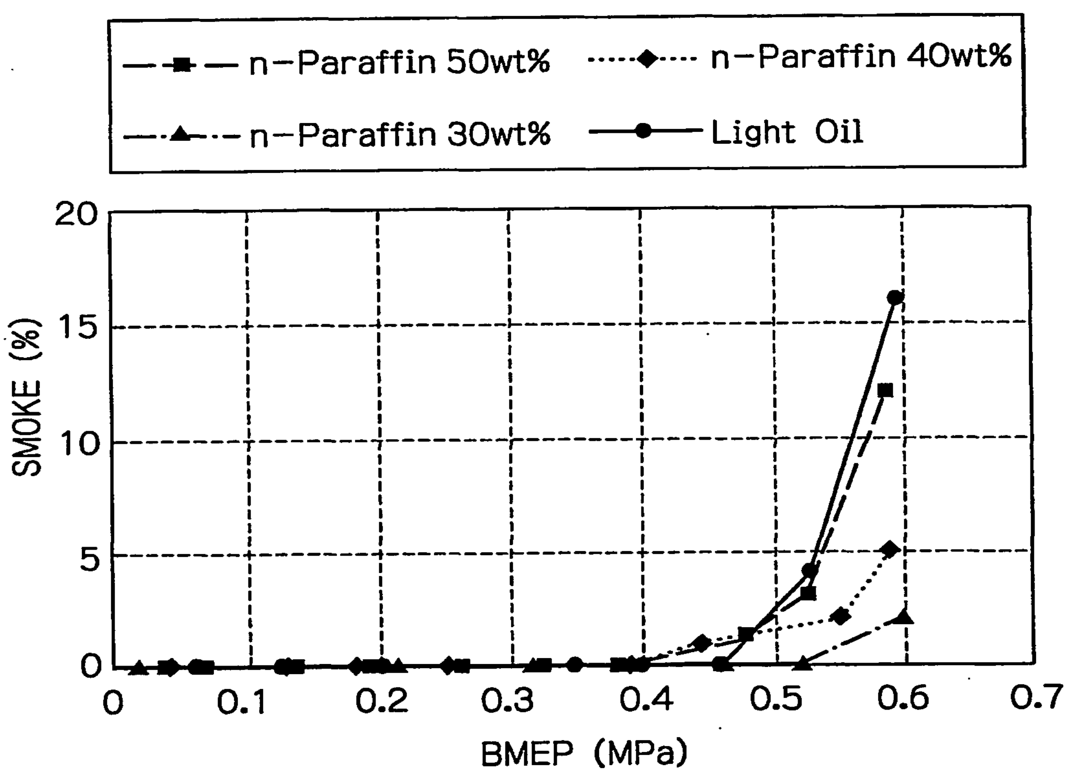
8. A fuel in accordance with claim 7, further added with a lubricity improving agent and a viscosity improving agent.

9. A fuel in accordance with claim 7, in which said

radical generating agent comprises at least one element selected from the group consisting of nitrate, nitrite, organic peroxide and azo compound.

10. A fuel in accordance with claim 7, in which said liquid hydrocarbon is at least one element selected from the group consisting of normal paraffin, naphtha, kerosene, light oil and heavy oil.

Fig. 1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n-Paraffin 40wt%
n-Paraffin 30wt%
Light Oil
SMOKE (%)
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15
10
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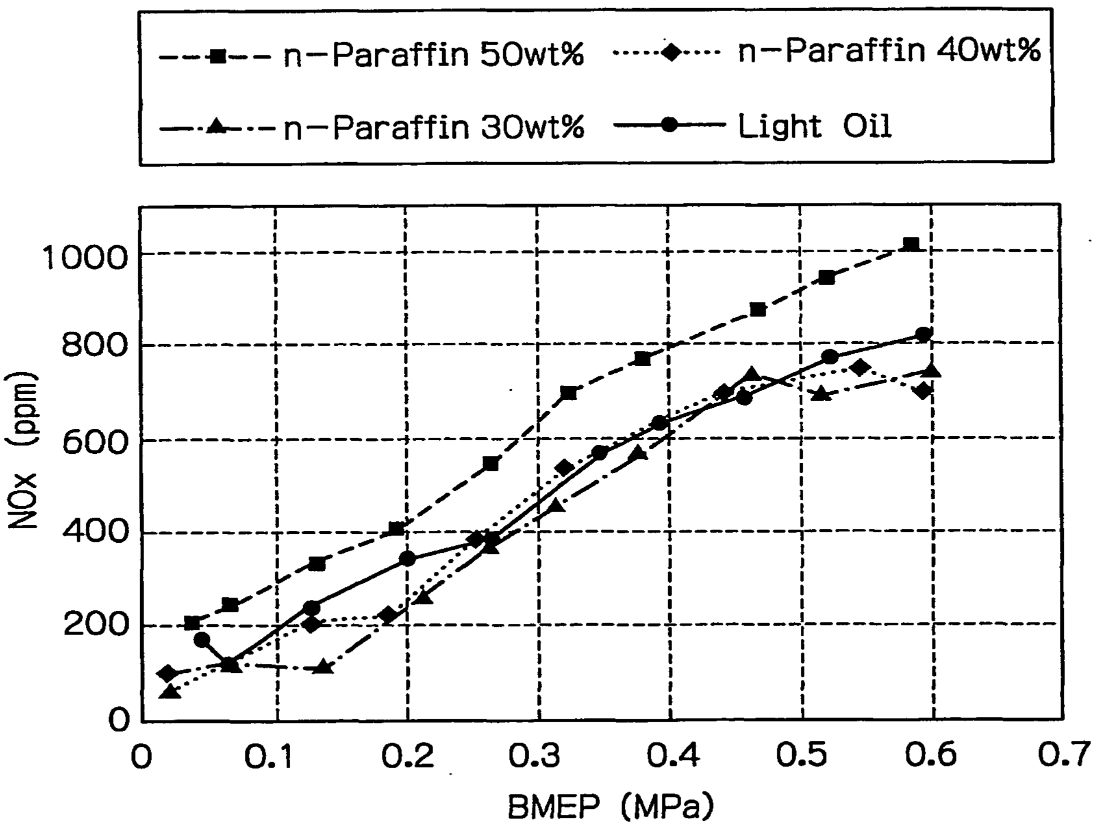
0.2
0.3
0.4
0.5
0.6
0.7
BMEP (MPa)

Fig. 2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n-Paraffin 30wt%
Light Oil
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400
600
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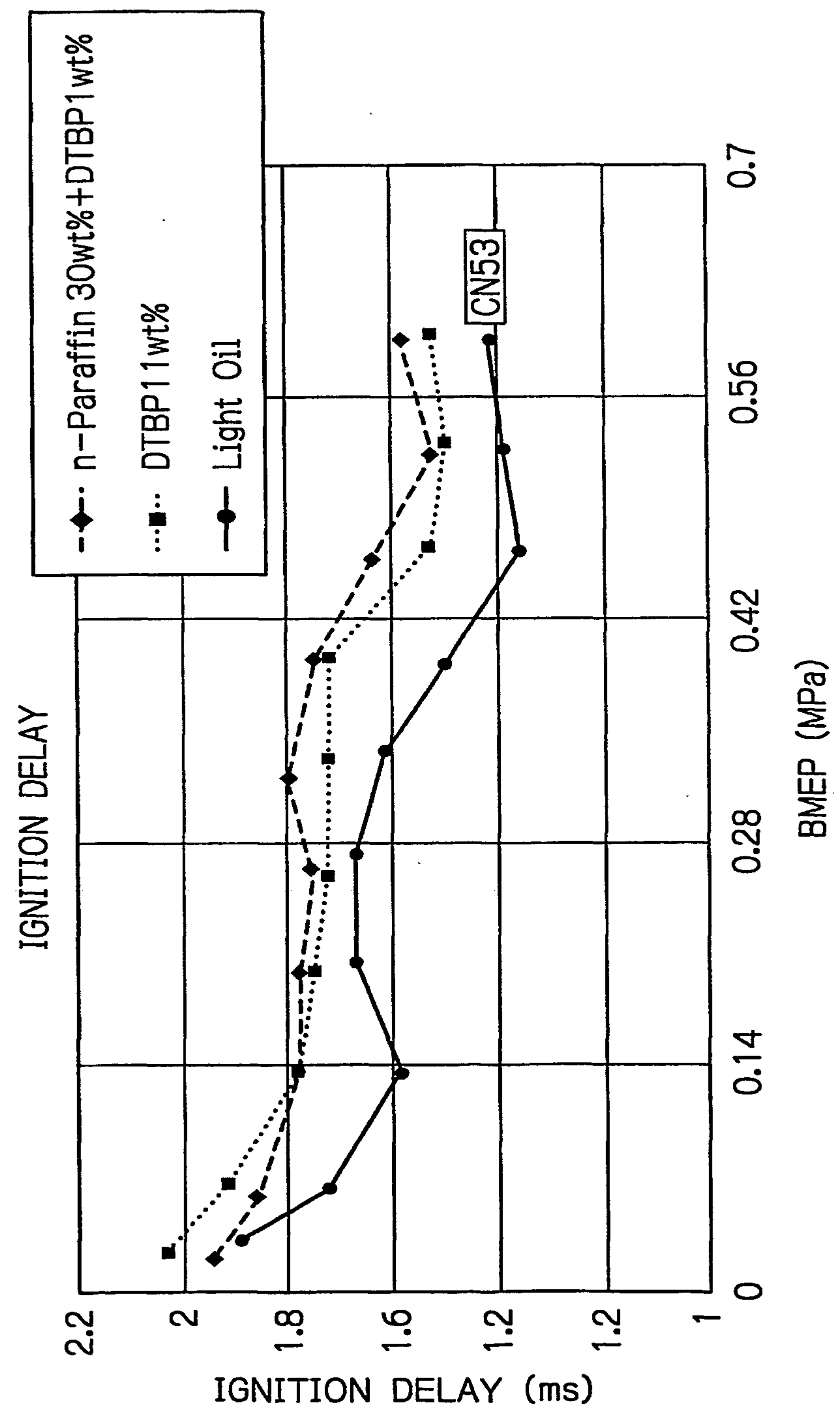
BMEP (MPa)

Fig. 3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DTBP11wt%
Light Oil
CN53
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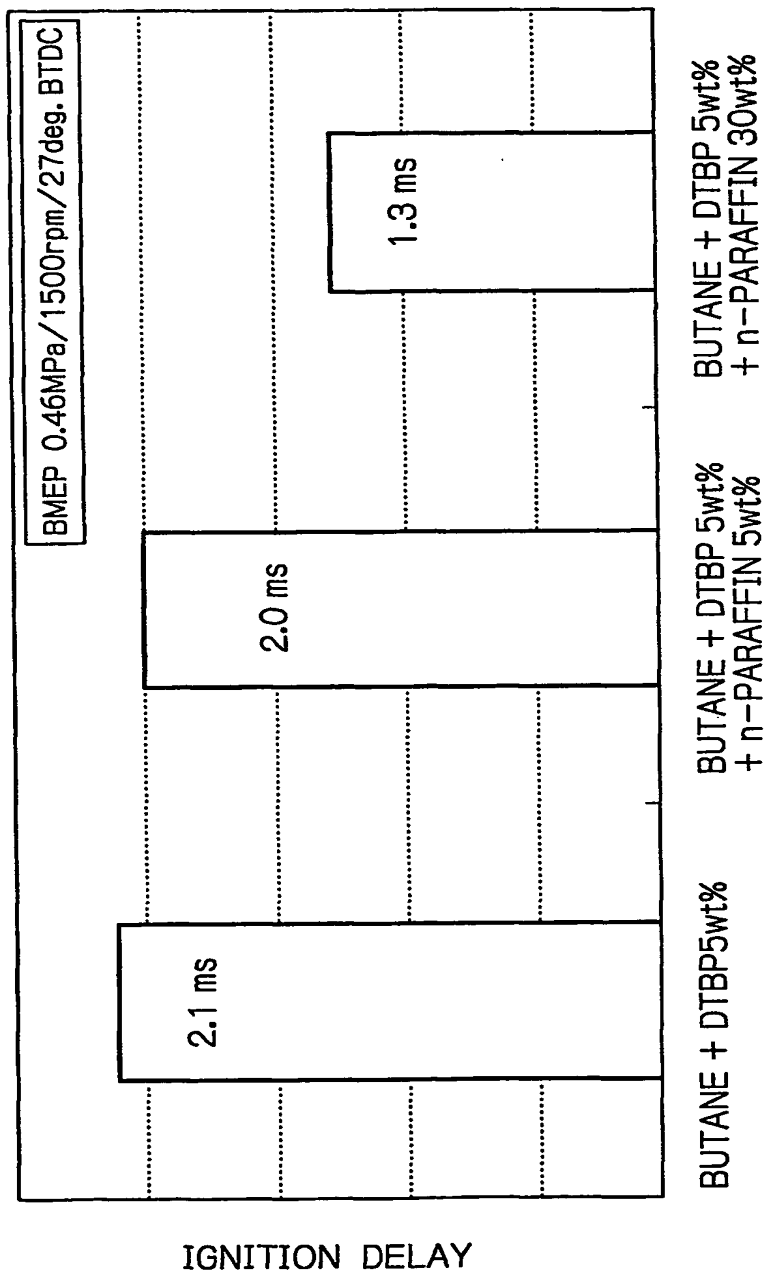
Fig. 4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BUTANE + DTBP5wt%
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BUTANE + DTBP 5wt% + n-PARAFFIN 30wt%
IGNITION DELAY

Fig. 5

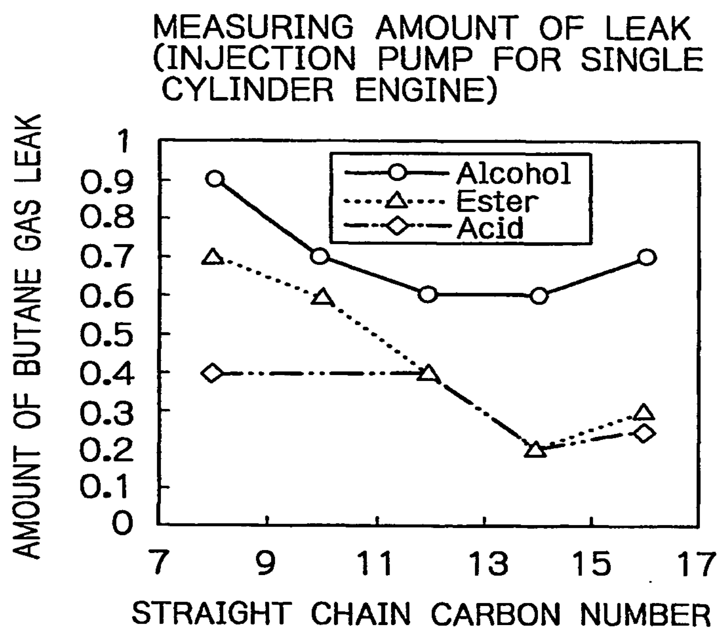

MEASURING AMOUNT OF LEAK
(INJECTION PUMP FOR SINGLE
CYLINDER ENGINE)
AMOUNT OF BUTANE GAS LEAK
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Alcohol
Ester
Acid
7
9
11
13
15
17
STRAIGHT CHAIN CARBON NUMBER

Fig. 6

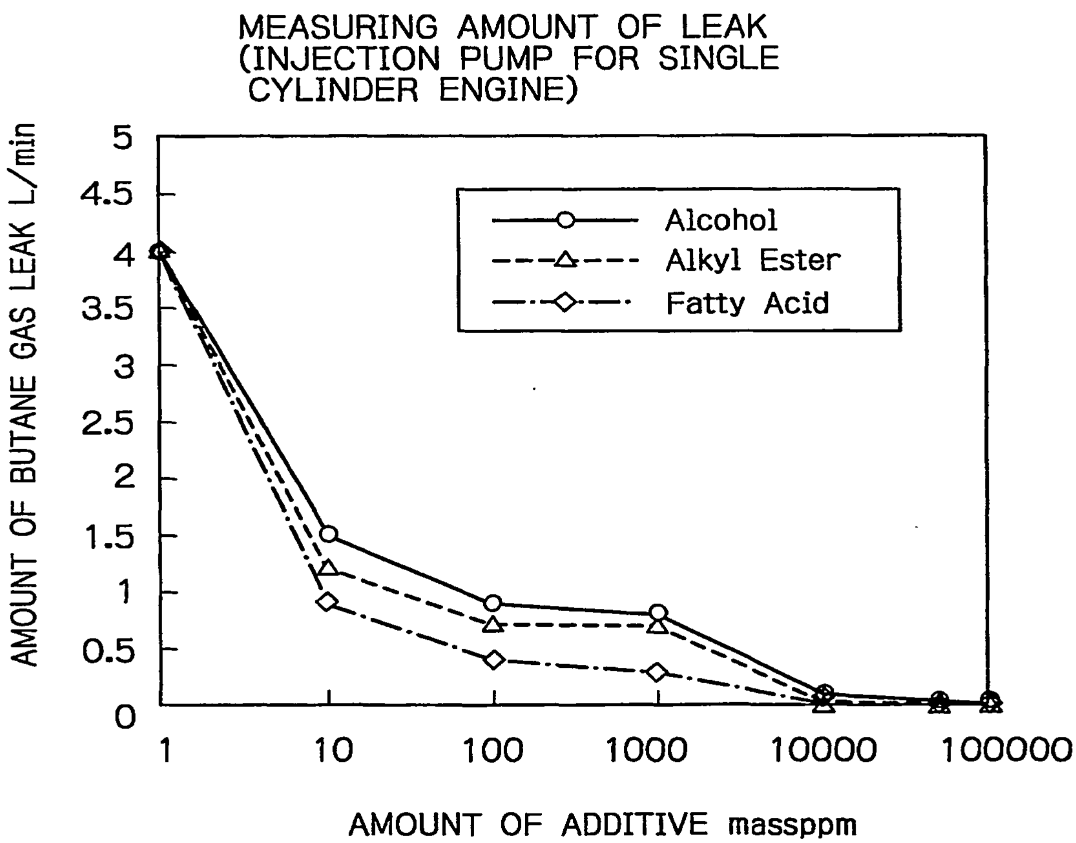
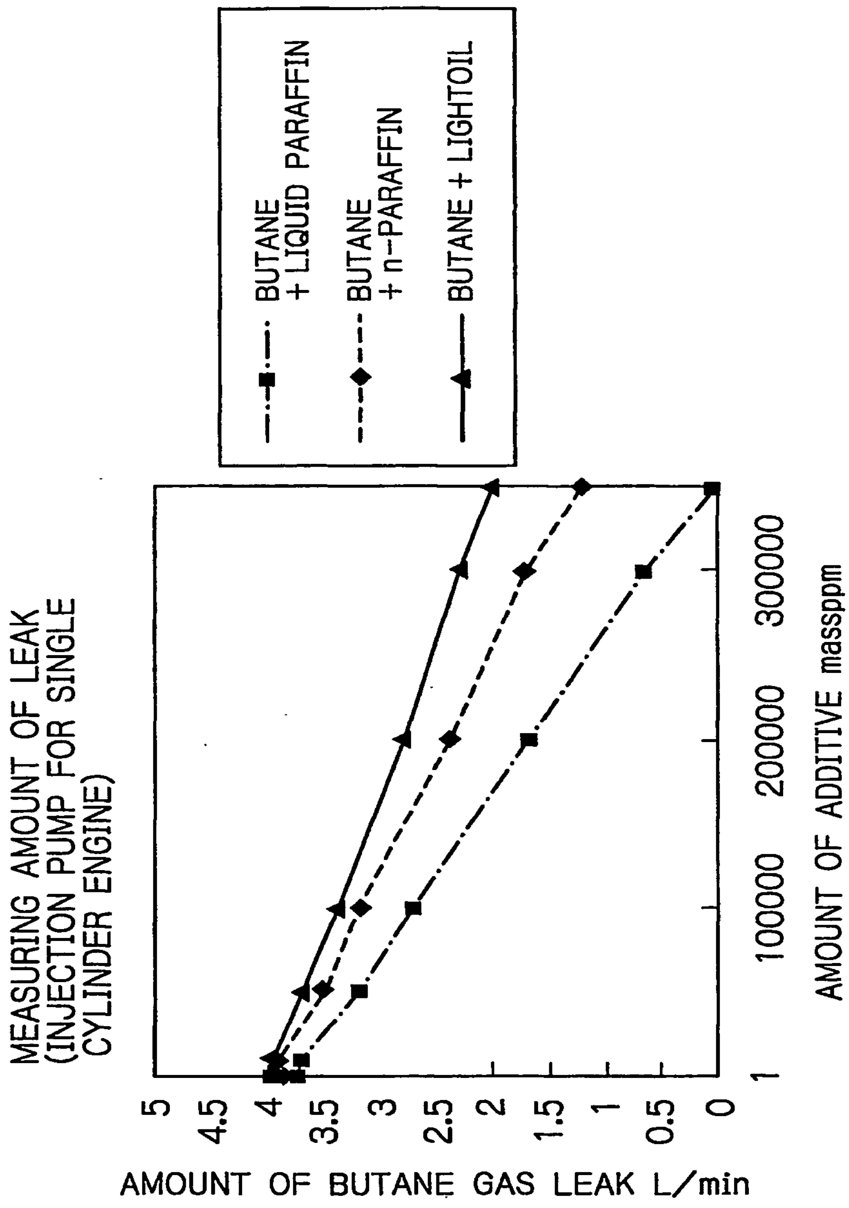

MEASURING AMOUNT OF LEAK
(INJECTION PUMP FOR SINGLE
CYLINDER ENGINE)
AMOUNT OF BUTANE GAS LEAK L/min
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Alcohol
Alkyl Ester
Fatty Acid
1
10
100
1000
10000
100000
AMOUNT OF ADDITIVE massppm

Fig. 7



MEASURING AMOUNT OF LEAK (INJECTION PUMP FOR SINGLE CYLINDER ENGINE)
AMOUNT OF BUTANE GAS LEAK L/min
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
AMOUNT OF ADDITIVE massppm
1
100000
200000
300000
BUTANE + LIQUID PARAFFIN
BUTANE + n-PARAFFIN
BUTANE + LIGHTOIL

Fig. 8

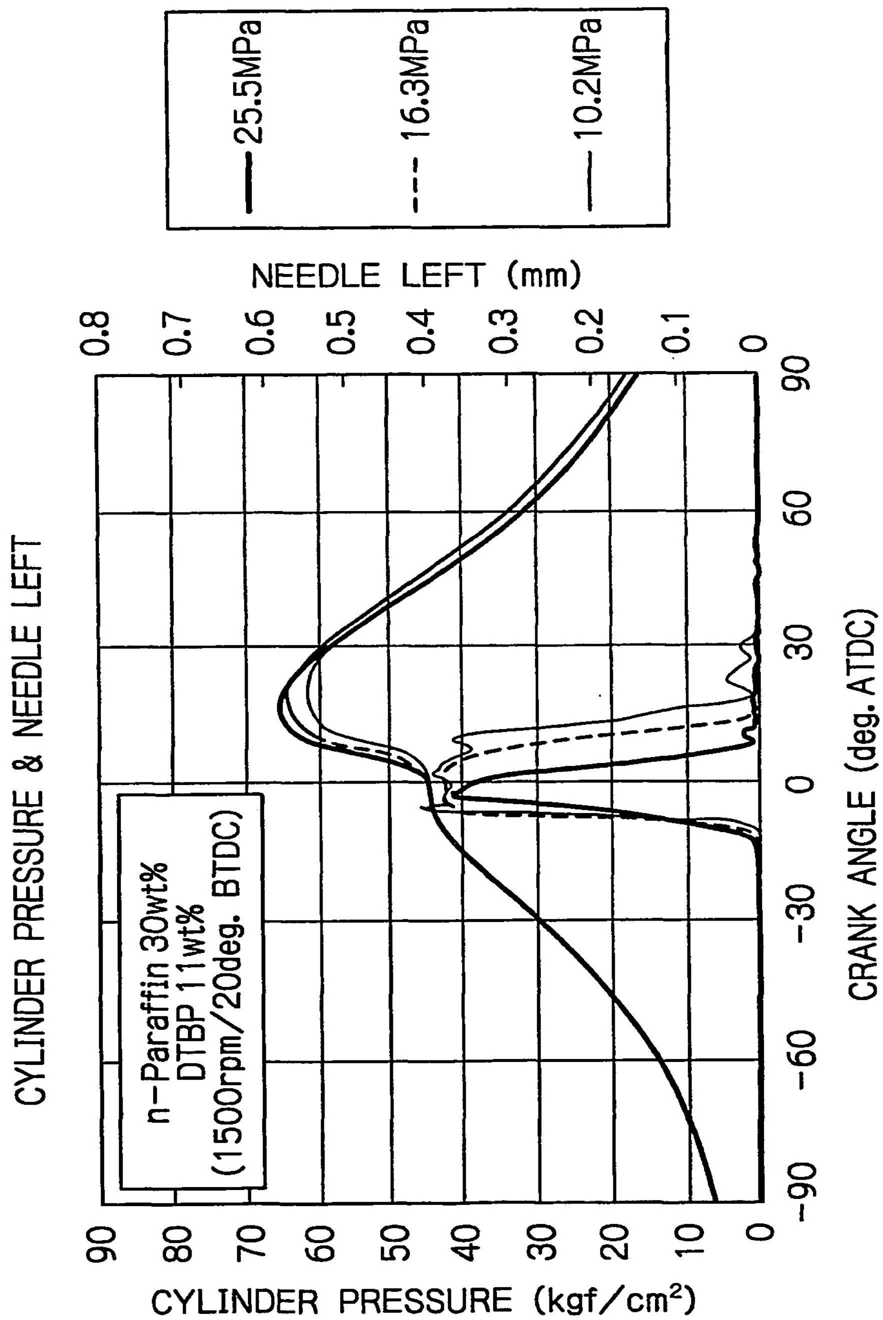

CYLINDER PRESSURE & NEEDLE LEFT
n-Paraffin 30wt%
DTBP 11wt%
(1500rpm/20deg. BTDC)
25.5MPa
16.3MPa
10.2MPa
NEEDLE LEFT (mm)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
90
80
70
60
50
40
30
20
10
0
-90
-60
-30
0
30
60
90
CRANK ANGLE (deg. ATDC)
CYLINDER PRESSURE (kgf/cm²)

Fig. 9

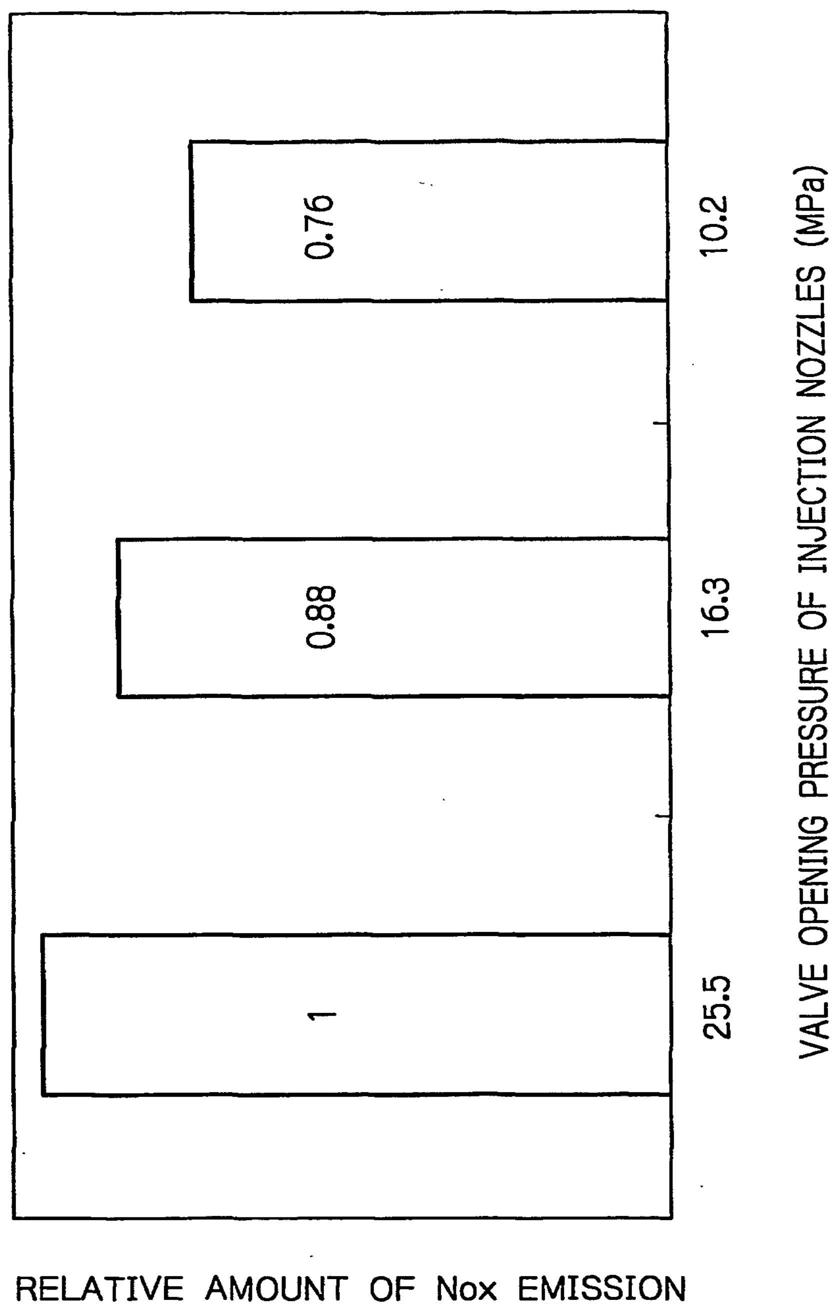

0.76
0.88
1
10.2
16.3
25.5
VALVE OPENING PRESSURE OF INJECTION NOZZLES (MPa)
RELATIVE AMOUNT OF Nox EMISSION

Fig. 10